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## Geometrical shape assessment of additively manufactured features by direct light processing vat polymerization method

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### Abstract

The importance of Additive Manufacturing (AM) in the field of micro manufacturing is increasing. Vat Polymerization Methods are one of the lead AM technologies to produce polymer micro parts. In the Technical University of Denmark (DTU), a vat photopolymerization AM machine able to print features in a micro scale was developed, build and validated. The work here presented analyses the capability of the machine in terms of geometry, when printing features of different sizes and geometries. For this study, two test parts have been designed, a circular stepped pyramid and a square stepped pyramid, both having micro size steps at the top of the pyramids. Five batches of each test part have been printed to evaluate the variability of the results in a single and in various prints.

**Keywords:** Additive Manufacturing; Vat Polymerization; Micro Manufacturing; Polymer;

### 1. Introduction

Additive Manufacturing technologies produce parts by adding material layer by layer, being able to fabricate parts with complex geometries that could not be fabricated using conventional manufacturing methods. The recent improvements in AM accuracy have allowed the production of micro features, introducing AM technologies, like Vat Polymerization (VP) Method, in the micro AM ( $\mu$ AM) field [1].

In order to achieve the best precision when printing micro features in a final product, it is important to know and understand the performance and capability of the AM machine. In this work, the performance of a VP AM machine is studied. For this purpose, two sample parts have been designed: a circular stepped pyramid and a square stepped pyramid. Five batches of each sample have been printed and the printouts have been analysed in terms of geometry and step height.

### 2. Method and Materials

#### 2.1. Digital Light Processing Technology

In a VP process, the liquid photopolymer resin is placed in a vat, where an Ultraviolet (UV) light is radiated, curing the liquid resin, layer by layer. When the UV light is radiated by a mask projector, the VP technology is called Digital Light Processing (DLP) [2].

This study evaluates the performance of a proprietary DLP machine (Figure 1) that was designed and built in the DTU [3]. In this machine, printing parameters are adjustable, such as layer thickness, light intensity and exposure time. In a previous work [4], the influence of these settings in the final quality of the part was studied. The selected parameters for this work are listed in Table 1.

After the sample has been printed, it is necessary to clean the liquid resin that has been left on it, using isopropyl alcohol. Once

the sample is clean, it must be left in a UV oven for 80 minutes to finish the curing process.

**Table 1.** Experimental Conditions

Parameters	Selected Parameters
Layer thickness/ $\mu$ m	25
Exposure time/s	3.5
Light intensity/mW	1.75
Resin	FunToDo red resin



**Figure 1.** Proprietary Digital Light Processing Machine

#### 2.2. Test Parts

Two tests parts have been designed with the shape of stepped pyramids considering two geometries: circular and square, as shown in Figure 2. Each pyramid has a total height of 2.4 mm, with steps of 100  $\mu$ m. The first and last step of the pyramids are a square/circle with a width/diameter of 4 mm and 20  $\mu$ m, respectively. The base of the part is 10  $\times$  10  $\times$  2.5 mm<sup>3</sup>.

### 2.3. Measurement Procedure

The Alicona Infinite Focus 3D Microscope has been used to perform the measurements. The chosen magnification lens are 10x for the geometries and 5x for the heights. The measurements have a vertical and lateral resolution of 200 nm and 3  $\mu\text{m}$  for 10x and 410 nm and 7  $\mu\text{m}$  for 5x, respectively. The software SPIP was used to analyse the obtained data.

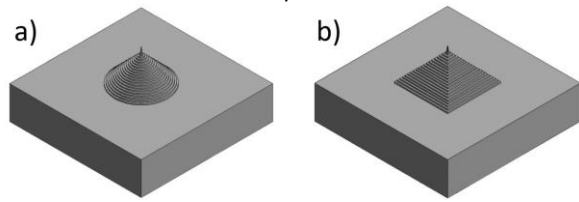


Figure 2. a) Circular stepped pyramid. b) Square stepped pyramid.

### 3. Results

The printing results have been evaluated in terms of geometry, smallest printed step and step height. In both test parts, the smallest printed step is at a height of 2 mm, with a nominal width/diameter of 200  $\mu\text{m}$ , in both cases the shape is distorted, being neither a circle nor a square, and the top is not a flat plane but a hump. The first printed step having the right square/circular shape is at a height of 1.9 mm and has a nominal width/diameter of 400  $\mu\text{m}$ .

The average height of the steps is similar for both tests parts: 102.31  $\mu\text{m}$  for the square stepped pyramid and 103.38  $\mu\text{m}$  for the circular stepped pyramid, having a reproducibility of  $\pm 4.2$   $\mu\text{m}$  and  $\pm 4.1$   $\mu\text{m}$ , respectively.

In terms of geometry, the squareness was evaluated for the square stepped pyramid as the deviation of the edges from the right angle. It has been observed that for all the batches the squareness was worst for the smallest features. In Figure 3, the standard deviations of the square edges from the right angle have been represented in the error bars for the steps with nominal widths of 400  $\mu\text{m}$ , 600  $\mu\text{m}$ , 800  $\mu\text{m}$  and 1000  $\mu\text{m}$ , considering the five batches. It must be noted that the average value of the 4 angles of each step is always 90°, for being a parallelogram.

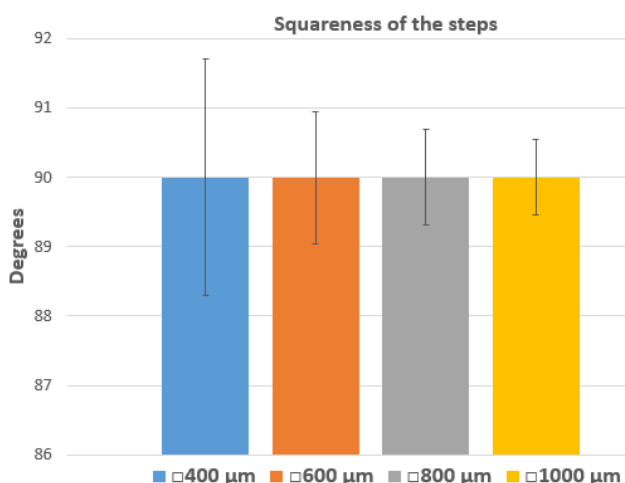


Figure 3. Squareness results for the square stepped pyramid.

The roundness was evaluated for the steps of the circular stepped pyramid, from 0 to 1, being 1 a perfect circle [5]. The average value of the roundness, considering the 5 batches, has been represented in Figure 4 for the nominal diameters of 400  $\mu\text{m}$ , 600  $\mu\text{m}$ , 800  $\mu\text{m}$  and 1000  $\mu\text{m}$ . The error bars represent the standard deviation of the roundness for each diameter, considering the 5 batches. As it can be observed, the roundness

result improves when the size of the circles increases, similarly to the squareness in the square stepped pyramid.

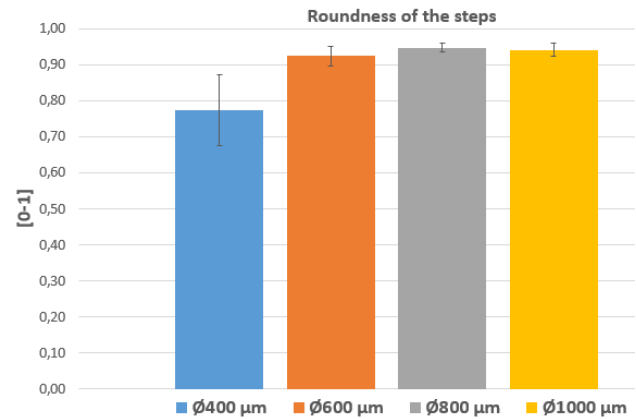


Figure 4. Roundness ([0-1]) results for the circular stepped pyramid.

### 4. Conclusions

In this work, the performance of a proprietary DLP AM machine has been characterized, using two test parts: a square stepped pyramid and a circular stepped pyramid. Five batches of each test part were fabricated. The terms that have been evaluated are: the smallest printed feature, step height and geometry. The obtained results for both test parts present the same trend.

The smallest printed feature in the pyramids of both test parts was the step with a width/diameter of 200  $\mu\text{m}$ . This last step printed did not have the desired square or circular shape, whereas it had the shape of a hump.

In both cases the step height was slightly higher than the nominal value and the standard deviation of the results was around  $\pm 4$   $\mu\text{m}$ .

In both test parts, the quality of the shape geometry was decreased for the smaller steps, achieving an acceptable quality and stabilizing at the step with a width/diameter of 800  $\mu\text{m}$ .

In future works, other test parts should be designed and printed, in order to study the effect of other geometries in the results. In addition, the effect of the machine settings in the test parts could be studied.

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